International Journal of Civil Engineering (IJCE)
ISSN(P): 2278-9987; ISSN(E): 2278-9995
Vol. 5, Issue 6, Oct - Nov 2016; 35-44

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations
IASET

DEVELOPMENT OF HIGH PERFORMANCE FIBRE REINFORCED CONCRETE USING SILICA FUME AND FLY ASH

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ABSTRACT

High performance concrete is a concrete mixture, which is designed to provide high durability and high strength when compared to the conventional concrete. The present study describes the development of High-Performance Fiber-Reinforced Concrete (HPFRC) with very high strength and durability properties. Initially, the optimum amount of Silica fume and fly ash needed to obtain concrete of desired compressive strength was determined by the partial replacement of cement with different quantities of Silica fume and fly ash. The mechanical properties and durability properties (limiting to water absorption test, sulphate attack and sea water attack) of High Performance Fibre Reinforced Concrete (HPFRC) were studied by varying the fibre content. The test results indicate that the incorporation of mineral admixtures and steel fibres improves mechanical and durability characteristics of the concrete.

KEYWORDS: Compressive Strength, Durability Properties, High Performance Concrete, High-Performance Fiber-Reinforced Concrete, Mechanical Properties

INTRODUCTION

Concrete is a composite material which is composed of aggregates that are bonded together with a fluid cement which hardens over time. Often, to improve the physical properties of the wet mix or the finished material, additives (such as pozzolans or superplasticizers) are included in the mixture. In concrete, a range of materials can be used as the cement such as mineral admixtures [1].

High Performance Fibre-Reinforced Concrete (HPFRC) is the combination of high performance concrete matrix and fibre reinforcement. High performance concrete possess high durability and high strength when compared to conventional concrete. High performance concrete may contains one or more of different cementitious materials such as Silica fume, fly ash, or ground granulated blast furnace slag and usually a super plasticizer [3, 5]. Even though it's initial cost is higher than that of conventional concrete, high Performance concrete works out to be economical. Because, the use of High Performance concrete in construction enhances the service life of the structure and the structure suffers less damage which would reduce overall costs [4].

The strength of concrete significantly increases by the inclusion of steel reinforcement. The development of micro cracks is a must to suppress, to produce concrete with homogenous tensile properties. The introduction of fibers was brought in as a solution to develop concrete in view of enhancing its flexural and tensile strength. When compared with

traditional reinforced concrete fibre reinforced concrete is rather a new engineering material. It is a new form of binder that could combine Portland cement in the bonding with cement matrices [2].

From the literature survey it can be concluded that the inclusion of steel fibres to cementitious materials improve many of the engineering properties such as tensile strength, fracture toughness, energy absorption etc [2]. Reviews indicate that there exists an optimal value of fibre content. When fibres added beyond this value, the overall improvement is not applicable. Hooked end steel fibres can be well distributed in the mix and the mechanical properties of concrete can be improved effectively. There is an optimum amount of Silica fume and fly ash for which, further increase in their content will not increase the strength parameters of concrete [3].

This paper aims to find the optimum amount of fly ash and Silica fume for the desired compressive strength of 110 MPa. And to find the mechanical properties of High Performance Fiber Reinforced Concrete limiting to compressive strength, split tensile strength and flexural strength using various percentages of steel fibres of aspect ratio 60 and also to find the durability properties of High Performance Fiber Reinforced Concrete such as water absorption, sulphate attack and sea water attack.

EXPERIMENTAL METHDOLOGY

Materials and Mix Proportion

The ingredients used in this study are Portland cement, fly ash, Silica fume, fine aggregate, coarse aggregate, steel fibre, superplasticizer and water.

Ordinary Portland cement 53 grade conforming to IS 12269-1989 was used in this study. Low calcium (ASTM Class F) fly ash with specific gravity 2.5. Silica fume conforming to IS 15388.2003 was used in this study, having specific gravity 2.2, specific surface 23000 m^2/kg and SiO_2 content greater than 85%. Fine aggregate used are M-Sand used confirms to IS 383:1970 Zone II having nominal size of 2.36 mm and specific gravity of 2.62. Coarse aggregate of nominal size 12.50 mm (70%) and 6 mm (30%) are used. Steel fibres used are hooked end type and of aspect ratio 60 (30 mm length x 0.5 mm diameter) and tensile strength of 1450 MPa. The super plasticizer used was Master Glenium ACE 30 a product of BASF India Pvt. Ltd, having pH greater than 6 and having chloride ion content less than 0.2%.

Proportioning of the mixtures were done according to the guidelines of American Concrete Institute. Mixture proportions for mixes of Silica fume and fly ash to get the optimum amount of admixtures to get the desired strength are summarized in Table 1.

Test Procedures

The compressive strength test and flexural strength was conducted as per IS 516:1959. The split tensile strength specimens are tested as per IS 5816:1999. Cubes of size 150mm were casted to determine the compressive strength of concrete. Split tensile strength was determined using cylinders of size 150mm dia and 300mm height. A beam of size 100 ×100 ×150 mm was made to find the flexural strength of concrete. 100 mm cubes were used to find the water absorption at 28 days of curing. 150 mm cubes are used to find both sulphate attack and sea water attack of specimens. Specimens are cured by submerging in clean, fresh water and kept there until taken out just prior to test. The values taken are average results of three specimens.

Stage 1: The first stage of the study includes the development of target strength by the partial replacement of cement by Silica fume and fly ash. Compressive strength and Split tensile strength were determined for all the combinations of Silica fume and fly ash.

Table 1: Mix Proportions for HPC (For 1 M^3)

Mix Id	W/Cm	C	F	S	Ca	Fa	Sp
$F_{12}S_8$	0.23	600	90	60	898.16	561.08	27
$F_{14}S_8$	0.23	585	105	60	898.16	561.08	27
$F_{16}S_8$	0.23	570	120	60	898.16	561.08	27
$F_{18}S_8$	0.23	555	135	60	898.16	561.08	27
$F_{12}S_{10}$	0.23	585	90	75	898.16	561.08	27
$F_{14}S_{10}$	0.23	570	105	75	898.16	561.08	27
$F_{16}S_{10}$	0.23	555	120	75	898.16	561.08	27
$F_{18}S_{10}$	0.23	540	135	75	898.16	561.08	27
$F_{12}S_{12}$	0.23	570	90	90	898.16	561.08	27
$F_{14}S_{12}$	0.23	555	105	90	898.16	561.08	27
$F_{16}S_{12}$	0.23	540	120	90	898.16	561.08	27
$F_{18}S_{12}$	0.23	525	135	90	898.16	561.08	27
$F_{12}S_{14}$	0.23	555	90	105	898.16	561.08	27
$F_{14}S_{14}$	0.23	540	105	105	898.16	561.08	27
$F_{16}S_{14}$	0.23	525	120	105	898.16	561.08	27
$F_{18}S_{14}$	0.23	510	135	105	898.16	561.08	27

Stage 2: In the second stage, the optimum content of Silica fume and fly ash was adopted for achieving HPFRC with different fibre contents. Mechanical properties (limiting to compressive strength, split tensile strength and flexural strength) and durability properties (limiting to water absorption, sulphate attack and sea water attack) of the HPFRC were determined. Fibre contents for developing High Performance Fibre Reinforced Concrete using the optimum amount of silica fume and fly ash are shown in Table 2.

Table 2: Fibre Content for HPFRC

Materials	Hpfrc1	Hpfrc2	Hpfrc3
Cement (kg/m^3)	555	555	555
Fly ash (kg/m^3)	135	135	135
Silica fume (kg/m^3)	60	60	60
Course aggregate (kg/m^3)	898.16	898.16	898.16
Fine aggregate (kg/m^3)	561.08	561.08	561.08
Superplasticizer (kg/m^3)	27	27	27
w/c	0.23	0.23	0.23
Fibre content (%)	0.75	1.00	1.25

RESULTS AND DISCUSSIONS

Stage 1: Compressive and split tensile tests were conducted to find the optimum amount of Silica fume and flyash.

The concrete specimens of different mixes were prepared. Specimens are cured by submerging in clean, fresh water and kept there until taken out just prior to test. The values taken are average results of three specimens. The percentage variations in compressive strength and split tensile strength with different admixture contents are shown in Figure 1 and Figure 2 respectively.

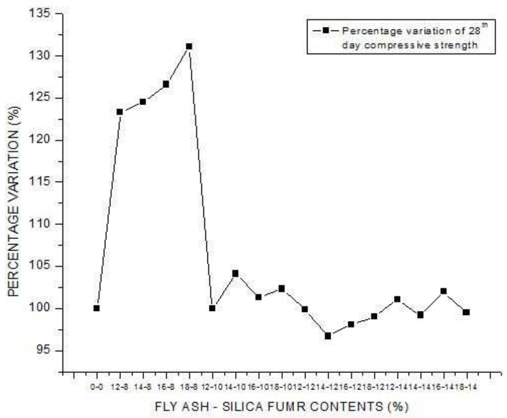

Figure 1: Variation of Compressive Strength of High Performance Concrete for Different Fly Ash Content and Silica Fume Contents

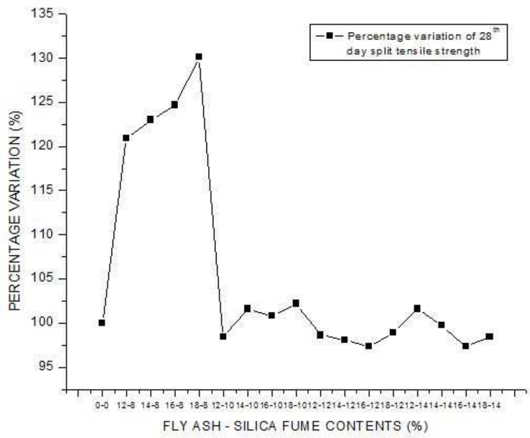

Figure 2: Variation of Split Tensile Strength of High Performance Concrete for Different Fly Ash Content and Silica Fume Contents

From the test results (Figure 1 and Figure 2) it can be seen that for a particular fly ash and Silica fume content (F_{18} S_8) the compressive strength and split tensile strength are maximum. A continuous increase in strength is observed up to this combination. Thereafter the compressive strength values decreases. This mix can be taken as the optimum quantity of silica fume and fly ash for obtaining the target strength.

Stage 2: After obtaining the optimum amount of Silica fume and fly ash for the desired compressive strength of 110 MPa, High Performance Fibre Reinforced Concrete specimens were casted using different fibre contents (0.75%, 1% and 1.25%).

Compression, split tensile and flexure tests were carried out for the HPFRC. The percentage increment of compressive strength and split tensile strength of concrete after the inclusion of steel fibre is shown in Figure 3 and Figure 4, respectively.

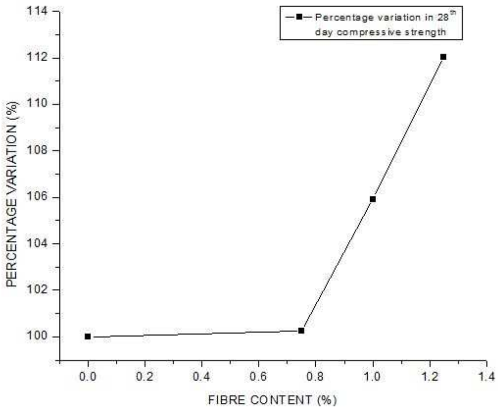

Figure 3: Variation of Compressive Strength of Concrete for Different Steel Fibre Contents

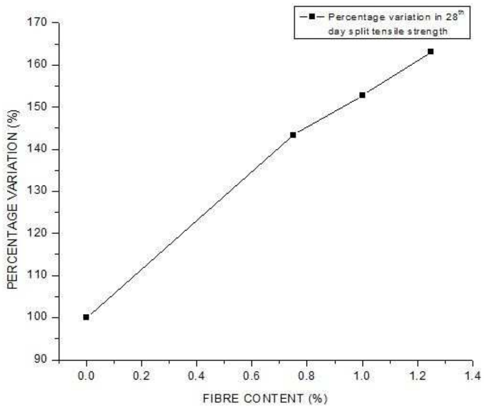

Figure 4: Variation of Split Tensile Strength of Concrete for Different Steel Fibre Contents

Initially tests were conducted to determine the optimum amount of silica fume and fly ash. And the maximum compressive strength was obtained to be 112.23 MPa. The inclusion of fiber increases the compressive strength of concrete at 28 days. A continuous increase in strength is observed after the addition of different fibre contents can be seen in Figure 3. The 1.25% fibre content has given the maximum compressive strength value of 125.74 MPa out of the three fibre contents. By the addition of hooked end steel fibres there is up to 12% increase in the compressive strength of the specimens.

Figure 4 shows the percentage variation of split tensile strength for different fibre contents. For high performance concrete without steel fibre the maximum tensile strength was obtained to be 4.80 MPa. For high performance steel fibre reinforced concrete there observed a continuous increase in the split tensile strength. By the addition of steel fibres there is up to 63% increase in the tensile strength of the specimens. 1.25% content of steel fibres shows considerable increase in tensile strength compared to 0.75% and 1%.

Effect of steel fibres on the flexural strength of concrete after 28 days of curing is shown in Figure 5.

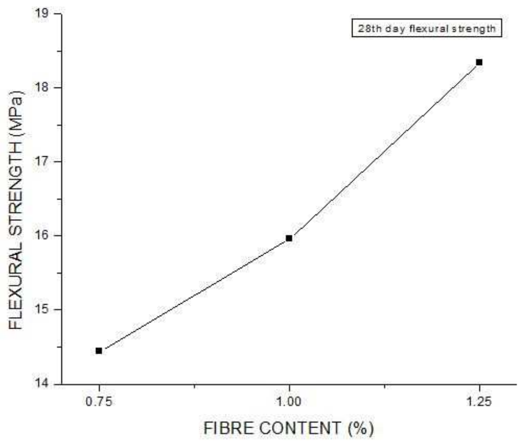

Figure 5: Effect of Steel Fibre on the Flexural Strength of Concrete

Figure 5: shows the effect of Silica fume and fly ash and fibres on flexural strength of a high performance fibre reinforced concrete. The fibre content is indicated on X-axis and flexural strength is on Y-axis. The result shows that the flexural strength of concrete increases considerably with an increase in fibre contents. A continuous increase in strength is observed up to a 1.25% of fibres content.

Stage 3: *DURABILITY PROPERTIES*

- **Water Absorption**

The concrete specimens (100 mm cubes) of different mixes were prepared. The percentage of water absorption of the hardened concrete after 28 days of curing containing various percentages of hooked end steel fibres are shown in Figure 6.

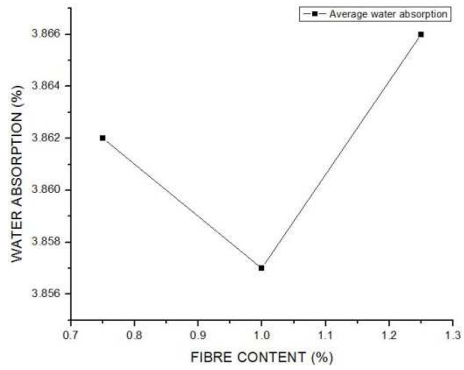

Figure 6: Water Absorption

The water absorption test result shows only a slight variation among the three fibre contents. Percentage water absorption was found to be lesser for 1% fibre content when compared with 0.75% and 1.25% fibre contents.

- **Sulphate Attack**

The concrete specimens of different fibre contents were prepared for the optimum mix. After 24 hours the specimens were immersed in water containing 2.0 % magnesium sulphate for 90 days. Weight loss and strength loss were obtained after 90 days and are shown in Figure 7 and Figure 8, respectively.

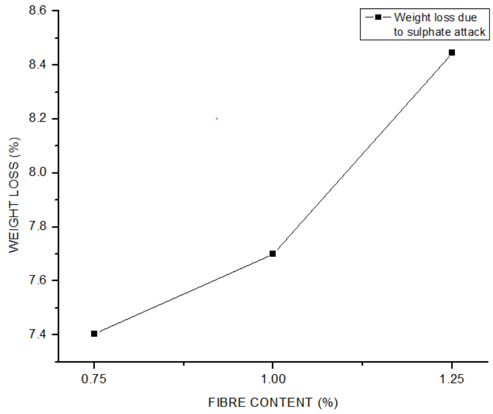

Figure 7: Weight Loss of Concrete Due to Sulphate Attack

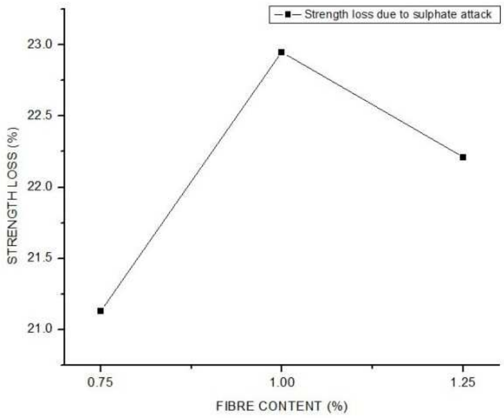

Figure 8: Strength Loss of Concrete Due to Sulphate Attack

Figure 7 shows the average weight loss due to sulphate attack after 90 days. The average weight loss is found to be in the range of 7-10 %. The average weight loss due to sulphate attack is more for 1.25% fibre content compared to the other two fibre contents (0.75 % and 1 %). The average weight loss is lesser for 0.75% fibre content.

Figure 8 shows the average percentages of strength loss due to sulphate attack. The average strength loss due to sulphate attack is found to be in the range of 26 to 30 %. And it is found to be more for 1% fibre content (29.45%) than the other two. This is more than that of the sea water attack (23.51%) for the same mix. The average strength loss due to sulphate attack is lesser for 0.75% steel fibres (26.80%). This is because, the inclusion of steel fibres minimize the interconnecting voids and bridge the cracks which leads to lesser penetration of sulphate ions into concrete. Steel fibers could reduce the rate of propagation of cracks and retard the performance deterioration of the concrete.

- **Sea Water Attack**

The concrete specimens of different fibre contents were prepared for the optimum mix. After 24 hours the specimens were immersed in sea water for 90 days. Weight loss and strength loss were obtained after 90 days and are shown in Figure 9 and Figure 10, respectively.

Figure 9 shows the weight loss due to sea water attack after 90 days of immersion of specimens in sea water. Weight loss is found to be in the range of 6 to 8 %. The average weight loss due to sea water attack is more for 1.25% fibre content (7.861%) compared to the other two fibre contents (0.75 % and 1 %). The average weight loss due to sea water

attack is lesser for 0.75% fibre content (6.129%).

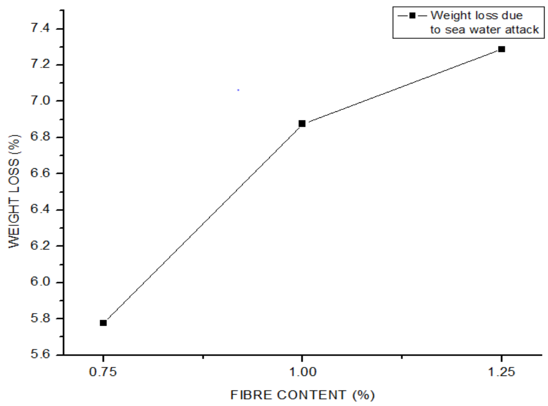

Figure 9: Weight Loss of Concrete Due to Sea Water Attack

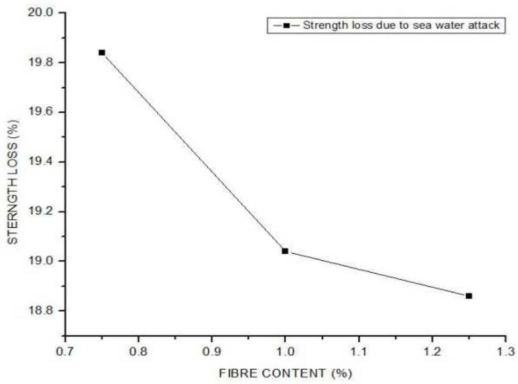

Figure 10: Strength Loss of Concrete Due to Sea Water Attack

Figure 10 shows the strength loss due to sea water attack after immersion of specimens in sea water for 90 days. The strength loss due to sea water attack is found to be in the range of 23 to 25 %. The maximum percentage of strength loss due to sea water attack is found to be 24.76% for 0.75 % fibre content. This is comparatively less than sulphate attack for the same mix of concrete. The average strength loss due to sea water attack is lesser for 1.25% steel fibre content (23.24%). This is because, magnesium and hydrogen carbonate ions precipitate a layer of brucite, on which a slower deposition of calcium carbonate occurs. These layers somewhat protect the concrete from attack by magnesium, chloride and sulphate ions, etc.

CONCLUSIONS

An experimental study was done to develop high performance fibre reinforced concrete by the partial replacement of cement using silica fume and fly ash and using steel fibres. From the study it is clear that HPFRC has got superior technical characteristics including strength and improved durability.

- Different percentages of silica fume and fly ash were considered to obtain the optimum quantity for the desired strength of 110 MPa. And it has been obtained in the range of 8% Silica fume and 18% fly ash.
- By using the optimum quantity of silica fume and fly ash, HPFRC was developed using hooked end steel fibres of aspect ratio 60. Different mechanical and durability properties were determined for the same.
- By the addition of steel fibres there is up to 12% increase in the compressive strength of the specimens. The

1.25% fibre content has given the maximum compressive strength out of the three fibre contents.

- A considerable increase in Spilt tensile strength (up to 63%) was observed for the HPFRC. 1.25% content steel fibres shows considerable increase in tensile strength.
- The maximum value of flexural strength was obtained for 1.25% fibre content..
- Durability properties such as sulphate attack, water absorption and sea water attack were also tested.
- The water absorption test result shows only a slight variation among the specimens with three fibre contents. Percentage water absorption was found to be lesser for 1% fibre content when compared with the other two fibre contents.
- The average weight loss due to sulphate attack is more for 1.25% fibre content compared to the other two fibre contents. The average weight loss due to sea water attack is more for 1.25% fibre content.
- The average weight loss is lesser for 0.75% fibre content for both sulphate attack and sea water attack.
- The strength loss due to sulphate attack is found to be in the range of 26 to 30 %. And it is found to be more for 1% fibre content than the other two. This is more than that of the sea water attack for the same mix.
- The average strength loss due to sulphate attack is lesser for 0.75% fibre content and the strength loss for sea water attack is lesser for 1.25% fibre content.
- Durability properties such as strength loss due to sulphate attack and sea water attack was found to be more for 1% and 0.75% fibre content, respectively.
- Addition of fibers up to 1.25% gives best results in all strength parameters compare to other fibre contents. While 0.75% fibre contents shows better durability properties.

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